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BUILDING ENERGY SIMULATION AND PARALLEL COMPUTING: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

Increased focus on energy cost savings and carbon footprint reduction efforts improved the visibility of building energy simulation, which became a mandatory requirement of several building rating systems. Despite developments in building energy simulation algorithms and user interfaces, there are some major challenges associated with building energy simulation; an important one is the computational demands and processing time. In this paper, we analyze the opportunities and challenges associated with this topic while executing a set of 275 parametric energy models *simultaneously* in EnergyPlus using a High Performance Computing (HPC) cluster. Successful parallel computing implementation of building energy simulations will not only improve the time necessary to get the results and enable scenario development for different design considerations, but also might enable Dynamic-Building Information Modeling (BIM) integration and near real-time decision-making. This paper concludes with the discussions on future directions and opportunities associated with building energy modeling simulations.

1 INTRODUCTION

Building energy efficiency has become the central topic of discussion worldwide due to greater emphasis on general sustainability, carbon footprint reduction, and ever-increasing utility prices. Moreover, the building energy efficiency is particularly of interest because of the overall amount of energy use and—seemingly—lack of innovation, typically due to the time it takes for a product under research and development to reach the masses. In the US, the building sector is responsible for about 40% of overall energy use, and 74% of all electricity use (DOE, 2012). The discussions on alternative energy sources are of value; however, much needed immediate benefits can be attained through implementation of energy-saving strategies. Understandably, evidence in the form of the emergence of building rating systems and government initiatives suggest that significant attention has been given to this thrust area. Building rating systems such as US Green Building Council's Leadership in Energy and Environmental Design (LEED) and Green Building Initiative's Green Globes have allocated a considerable credit weight to energy efficiency improvements—the newer versions of LEED and Green Globes rating systems for new construction allocate approximately 27% and 39% for operational energy use respectively (USGBC 2014, Srinivasan 2013). Moreover, government initiatives such as Energy Star have also been extended to the building sector.

Regardless of these efforts, the literature reviewed did not indicate consistent improvements in building energy use numbers, especially of those in "green buildings" (Newsham, Mancini, and Benjamin 2009; Scofield 2009; Menassa et al. 2012). Although the details of these discussions are beyond the scope of this paper, one problem cited in majority of these articles, and of great concern, is the inconsistencies between building energy predictions and actual, operational energy use data. Although there are some outlines proposed in building rating systems to award operational efficiency such as ASHRAE Building Energy Quotient Program (BEQP), the overwhelming majority of energy related points are awarded prior to the building being occupied, or in some instances, before one year of building occupancy. Because of the possible lag between building construction completion and fully operational energy use data availability, this credit award approach is likely to be the major hindrance towards actual energy efficiency.

Energy use prediction of new construction and existing buildings for evaluating potential energy-saving strategies are performed in DOE approved software (see section 1.1 for details). Among other issues, the time it takes to model, execute, simulate, and analyze results is significant and may pose a problem for building professionals to evaluate multiple scenarios prior to implementation. In some cases, building design engineers may opt for solutions without conducting detailed energy simulation owing to time constraints, particularly with tight project deadlines, budget, and professional fees. Although it is hard to determine whether this narrow focused approach to building energy simulation contributes to the cited simulated-measured energy differences, improved process time has the potential to reduce this discrepancy. Moreover, with the recent development of a Dynamic-Building Information Modeling (Dynamic-BIM) Workbench, a unified, interdependent, and interoperable platform for domain modeling, simulation, and visualization for energy and environmental assessments of buildings (Srinivasan et al. 2012, 2013), near real-time energy simulation is a necessity to communicate with building stakeholders through energy saving scenarios and hence the authors' interest in this study (Figure 1.).

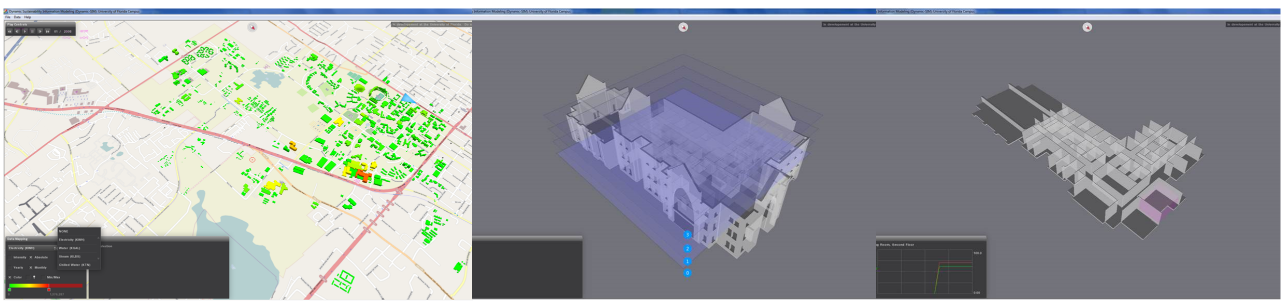

Figure 1: Dynamic-BIM Workbench showing real-time high-level energy use data (left), building geometry (middle), and thermal zones with real-time sensor data (right).

1.1 Building Energy Modeling Basics

Building energy analysis tools may be broadly classified into system sizing and system performance evaluation tools (Axley 2004). While system-sizing tools help in sizing individual components, system performance evaluation tools simulate a system to specified excitations. Tools may be differentiated into macroscopic analysis tools—those that utilize fundamental conservation principles providing a whole-system analysis rather than room-specific data, and microscopic analysis tools—those that utilize partial differential equations to evaluate spaces. DOE's DOE-2 engine and US Department of Defense's (DOD) BLAST engine aided the development of building energy analysis tools. EnergyPlus engine is the convergence of DOE-2 and BLAST and is maintained by Lawrence Berkeley National Laboratory. Currently, building energy analysis tools include software tools for building energy and renewable performance simulation. Although most of these tools have undergone mandatory validation as required by DOE, they still do not comprise all possible design strategies (Crawley et al. 2005). In some cases, only a few tools have integrated new strategies and developments in building technologies. For example, variable refrigerant flow systems have been deployed for cooling/heating for more than a decade, but currently only a handful of software tools can simulate such systems (e.g., Trane Trace 700, EnergyPro, etc.). The software tools use variants of the energy simulation engine; for example, eQuest and

VisualDOE use different versions of DOE-2 engine, while DesignBuilder uses the EnergyPlus engine, and Trane Trace™ 700 uses its proprietary engine. Therefore, given the same geometrical design data and strategies, the results may vary if two software tools are used to implement the same design. For building energy analysis, envelope thermal performance calculation is a critical component that calls for further development for the reasons stated below.

In this study, we have focused on EnergyPlus as it is freely available, and was used extensively by earlier researchers. EnergyPlus is a robust building energy simulation algorithm that combines the power of heat and mass balance simulation with building systems simulation. The significant improvement in this software over others is that at every time-step feedback from the building system simulation on loads is reflected in the next time-step of load calculations for adjusting space temperatures. This feedback mechanism provides an accurate representation of space temperature prediction, which is crucial for evaluating energy-saving strategies. However, the major drawback of such an integrated feedback system is that it takes several times longer when compared to other algorithms used to estimate building energy use. Among others, the processing time of energy simulation algorithms is a crucial component for the greater utilization by the design-engineering community.

2 RUN TIME REDUCTOIN IN BUILDING ENERGY SIMULATION

Existing literature seems to confirm the issues affiliated with processing requirements and run time of building energy simulation. Drawing from earlier discussions on the need for scenario development and dynamic-BIM integration of energy simulation, the processing (run) time reduction is a priority to enable widespread adoption. There are three main methods used in literature to improve computational requirements; model reduction, parametric analysis, and parallel computing.

- *Model Modification:* The idea behind model modification is to reduce the computational requirements through changing the model characteristics. Two examples of these are *model simplification* (Dobbs and Hencey, 2013; Akhtar, Borggaard, and Burns 2009) and *coarse-grain method* (Flood, Issa, and Abi-Shdid 2005). These methods offer improvements in processing time while providing acceptable/near accurate solutions. The main disadvantage of these methods appears to be the compromised accuracy. Considering the recent improvements in processing power, and differences in performance of these methodologies—in terms of accuracy and proposed improvements in processing time—they were excluded from this study.
- *Parametric Runs:* The second alternative proposed in the literature was to run multiple simulations through a range of parameters defined in the input files to enable sensitivity analysis of the energy simulations (Zhang 2009; Hong, Buhl, and Haves 2008; Eisenhower et al. 2012). It appears the goal of using parametric analysis was not to accelerate individual run times for simulations, but rather improve overall decision-making power by analyzing multiple scenarios. This alternative provides a plausible solution for EnergyPlus simulations as the software is designed to allow this with little-to-none changes to the program.
- *Parallel (Sub-Interval) Simulation:* The most inherently obvious choice of improving the processing time is using multiple processors/cores for running a single simulation; however, the method employed to achieve a similar result was to divide the simulations into smaller time intervals as the simulation run time is proportional to the length of the simulation period—i.e. running multiple monthly simulations rather than a single annual simulation (Hong, Buhl, and Haves 2008). The results of the sub-interval simulations results can then be aggregated into desired duration with higher accuracy levels (Garg et al. 2011, 2014).

To test the above-discussed methods of parallel computing, we used an HPC cluster network that comprised of 1924 processors. The focus of the study is to conduct concurrent parametric analyses using sub-interval parallel computing for a case study, which to the best of authors' knowledge has not been integrated within each other before, although both methods are extensively studied in literature separately. The basic premise of this study is the potential run time improvements with minimal fore planning and input. For details of different methods of parallelization discussed here, the readers are referred the cited references. The following sections discuss the case study building used for this analysis, HPC computing details and analysis of the results.

3 PARAMETRIC ANALYSIS USING SUB-INTERVAL PARALLEL COMPUTING: A CASE STUDY

Pugh Hall is located in the historic section of University of Florida's campus in Gainesville, Florida, USA, and has a total floor area of 40,150 sq. ft. This four-story building has a large teaching auditorium as well as public space for lectures and events, classrooms and seminar rooms, a two-story atrium, conference, office and other support spaces. Completed in 2007, the Pugh Hall incorporates a number of green building features and, in 2009, achieved LEED for New Construction 2.2 Silver rating from the U.S. Green Building Council. Falling in ASHRAE Climate Zone 2, Pugh Hall received a total of 36 silver points in the different LEED categories and thus demonstrates a high energy and water efficiency, and indoor air quality. Some of the features include high efficiency lighting and automatic controls, high performance glazing, ventilated attic space, low flow toilets and water conserving showers, use of low Volatile Organic Compound materials and thermal comfort permanent monitoring system.

A computer model of the Pugh Hall was generated using the DesignBuilder and EnergyPlus. The initial phase of the modeling consisted of study and collection of the architectural, mechanical and electrical data required for model input. The building was divided into 50 thermal zones for the purpose of analysis (Figure 2a.-2d.). The thermal zoning was completed with assumptions and also taking into consideration the space usage and HVAC systems. In some areas, perimeter zoning was done to account for additional cooling loads due to solar gain at the boundaries. The internal loads such as lights, people and equipment were estimated using building plans and ASHRAE/ANSI/IESNA Standard 90.1-2007. Data regarding the walls, roof, windows were obtained from the construction documents and were used to complete the geometry of the building. Different schedules such as heating & cooling, occupancy, equipment, domestic hot water were developed using the California ACM Manual. The HVAC system of the building was modeled using the Detailed HVAC option in DesignBuilder. For simplification purpose, one Air Handling Unit (AHU) was assigned to serve the large auditorium while two other AHU's were combined to serve the other areas of the building. The inputs consisted of the zone sizing inputs followed by the air-side equipment inputs and water-side equipment inputs.

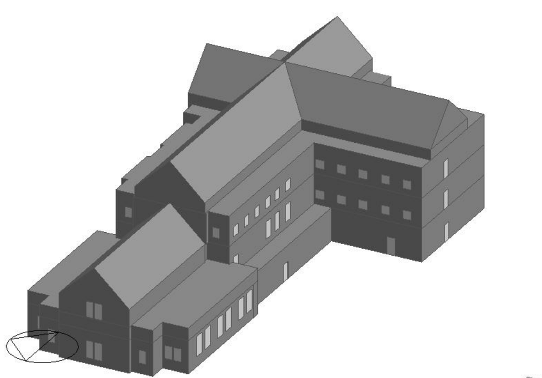

Figure 2a: Building model in DesignBuilder.

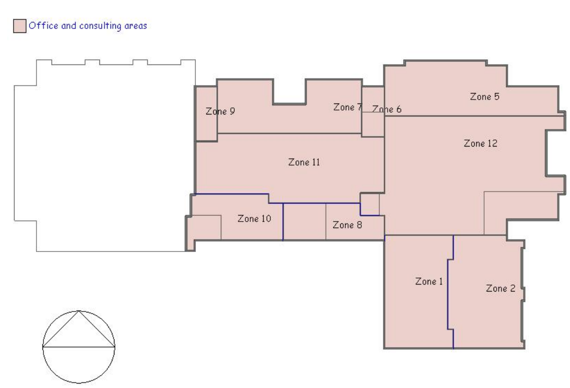

Figure 2b: First floor thermal zone layout.

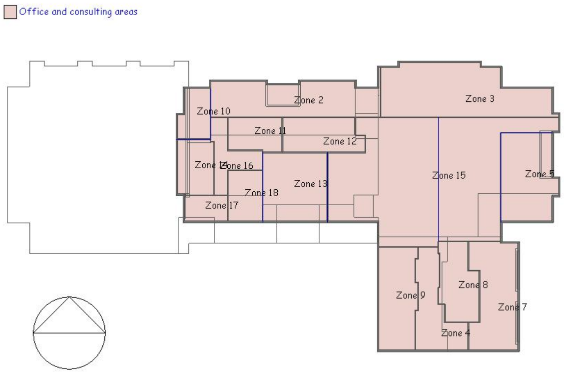

Figure 2c: Second floor thermal zone layout.

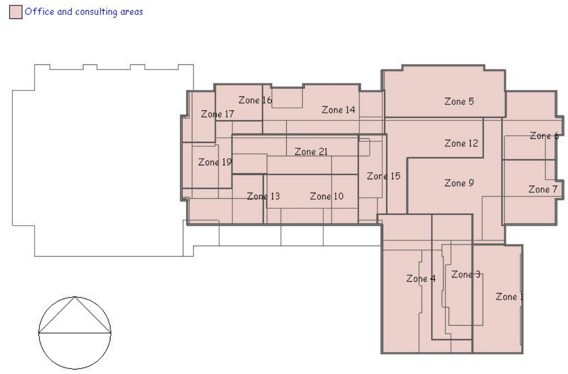

Figure 2d: Third floor thermal zone layout.

3.1 HPC Cluster Network Implementation

The HPC system used for this study is part of a larger system composed of 420 X5650 (2.66 GHz, 64bit, 6 core processors), 1472 E5-2670 (2.66 GHz, 64bit, 8 core processors), and 32 E7-8837 (2.66 GHz, 64bit, 8 core processors) Intel Xeon processors with a total of 15,264 GigaBytes of main memory. In specific, E5-2670 processors (one core per simulation) and 2GB of memory were used for this study—these computational allocations were specified for each simulation run.

Concurrent parametric simulations (Zhang 2009) using sub-interval parallel computing (Garg et al., 2014) with minimum modifications and computational effort was implemented. For parametric analysis, two parameters—thermal conductivity of window glazing material with five discrete options, and equipment power density that was varied ±25% (in 5% increments from its nominal value)—were considered. These two parameter variations resulted in 55 discrete scenarios. For sub-interval simulations, quarterly duration was chosen, resulting in four separate simulations, and these were also run in parallel to derive annual simulation values. In total, 275 simulations were run concurrently out of which 220 were quarterly simulations and 55 were annual simulations to create baseline for comparisons for speed and accuracy. As the IDF files are in plain text format, creating multiple IDF files representing individual parametric model is a straightforward and speedy process after the initial IDF file representing Pugh Hall was created. All simulations were sent to HPC cluster network at the same time and the overall processing times were recorded. It should be noted that the processing is not instantaneous and wait time, i.e., time between HPC submissions to start of simulation, varies among different runs. This happens as the HPC is shared with a number of users; however, this doesn't affect the processing times, and actual processing times for different runs were recorded and used as the basis of the discussions.

3.2 HPC Run Time: Discussions

The analyses results are consistent with the earlier literature in terms of accuracy and run time performance. We have not included the accuracy comparison tables, i.e. annual Energy Use Intensity comparisons, as the largest discrepancy among different options was in the range of 0.01 kBtu/sf for the annual values. Table 1. displays the average of the four quarterly simulation results across 55 scenarios. Although in earlier literature effects of parameter selection and simulation performance is discussed (Hong, Buhl, and Haves 2008), the results across the parameters analyzed here do not present any noticeable trends, and are somewhat similar across parameters and for different quarters.

Table 1: Parallel (sub-interval) run time statistics (in minutes).

Run	Mean	SD	Run	Mean	SD	Run	Mean	SD	Run	Mean	SD	Run	Mean	SD
1.1	10.62	2.36	2.1	9.25	2.44	3.1	9.94	1.83	4.1	9.90	0.71	5.1	9.78	1.65
1.2	9.38	2.01	2.2	9.21	0.41	3.2	8.62	0.39	4.2	9.68	1.30	5.2	9.73	1.78
1.3	9.37	1.98	2.3	9.16	0.35	3.3	8.87	0.42	4.3	9.56	1.66	5.3	9.77	0.62
1.4	8.75	0.59	2.4	8.69	0.51	3.4	9.77	1.42	4.4	9.64	1.28	5.4	9.15	0.37
1.5	9.68	0.86	2.5	9.20	1.12	3.5	10.39	2.09	4.5	9.64	1.28	5.5	9.96	0.78
1.6	9.00	0.87	2.6	9.50	1.77	3.6	10.06	1.76	4.6	9.88	1.25	5.6	9.70	1.16
1.7	8.69	0.74	2.7	9.23	1.18	3.7	10.45	1.97	4.7	9.81	0.91	5.7	9.76	1.00
1.8	9.55	0.71	2.8	9.73	0.72	3.8	11.82	3.59	4.8	9.85	1.07	5.8	9.90	0.68
1.9	9.63	1.49	2.9	9.73	0.67	3.9	9.79	1.69	4.9	8.76	1.15	5.9	9.75	0.79
1.10	10.46	1.83	2.10	9.44	1.13	3.10	10.06	1.57	4.10	8.96	0.58	5.10	9.25	1.11
1.11	9.68	1.94	2.11	9.44	0.69	3.11	9.33	0.71	4.11	8.96	0.88	5.11	10.74	1.88

Figure 3. displays the results of the annual simulation run time when compared to the longest quarterly time for a given scenario, which determines the length of the parallel computing. Note that the run time improvements are obvious from the plot; however, they are not linear with the number of parallel processes—a similar finding to those of Garg et al. (2011, 2014). It should also be noted that we assumed aggregating the quarterly simulation data into annual simulation will not take considerable time and the parallel run time is determined by the completion time of the slowest of quarterly simulation.

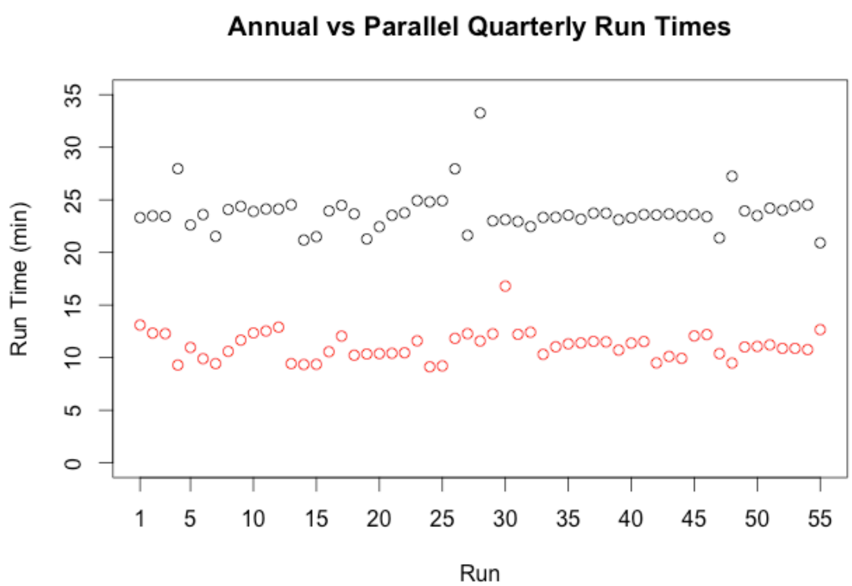

Figure 3: Run time comparison between annual and parallel simulation.

4 CONCLUSIONS AND FUTURE DIRECTIONS

This study was designated around a case study analyzed by parallel computing principles using EnergyPlus. Two parallelization options are used: running multiple parameters and dividing the annual simulations into quarterly parallel processes. Although the improvements with these two methods were obvious, perhaps a greater avenue for future development is further improving the simulation run time to enable near real-time building energy simulations for use by building stakeholders using integrated platforms such as Dynamic-BIM Workbench. Moreover, the complexity of parametric modeling increases exponentially when the parameters involve not only changes to target temperature, supply temperature, and velocity, but other significant design changes such as room length, width, height, window location, and size. With a robust parallel computing approach, near real-time building energy simulations can be achieved in such rigorous parameter variations offering design engineers a better tool for energy optimization.

As discussed earlier an obvious selection for parallelization would be using multiple processing units for a given simulation. This is referred to as multithreading in the EnergyPlus user manual. As the name suggests, the idea is to use available multiple cores as the standard for simulation run time improvement. Interestingly, the Windows version of the EnergyPlus software has an option for multithreading; however, enabling this option and running two simulations with one and four cores on a personal computer didn't show any improvements in run times. This is a similar finding to those of Hong, Buhl, and Haves (2008), although the authors used a different version (2. 2.2.0.023) whereas we used version 8.1.0. To further analyze this, we have looked into the source code of the EnergyPlus (version 8.0), and it appears the software code does not support and surpasses multithreading; even though, the user manual and software options suggest that multithreading is supported. Parallel computing in EnergyPlus is a viable alternative and is likely to improve the state of practice significantly provided near real-time analyses can be run. Currently parametric and subinterval runs seem to work without significant effort and provide reasonable improvement; however, they left much to be achieved if the goal is to enable near real-time energy simulation. Achieving near real-time simulations can enable dynamic-BIM integration, which has significant benefits far beyond the technical decision-making in energy efficiency. Perhaps the biggest benefit would be to increase stakeholder involvement and as an outreach tool to educate and train the masses in the effects of building design decision-making and long-term effects of energy performance and cost.

There are a few obstacles that need to be addressed before these can be achieved. The multithreading option is an inherent necessity and a revision to the EnergyPlus source code might be the answer. Another significant dynamic-BIM integration is the extension of parametric analysis into geometric elements. From the limited scope of this article it appears the parameter we have chosen have limited influence on building energy performance (at least for the simulation results), and it would appear the geometric changes to potential building design would be more problematic to accommodate in IDF files. There is also value in identifying parameters—both traditional and geometric—with significant effects on energy efficiency to increase the efficiency of simulation efforts from a sensitivity analysis perspective.

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